EVALUATION OF POSSIBLE DIRECTIONS FOR IMPROVING TRAFFIC MANAGEMENT SYSTEM

Babak Mehran, PhD
NSERC Industrial R&D Postdoctoral Fellow
IBI Group
230 Richmond Street West, Toronto ON M5V 1V6 Canada
Tel: 416 596 1930 ext. 206, Fax: 416 596 0644
Email: babak.mehran@ibigroup.com

Number of words = 5,800
Tables and Figures (5 @ 250 words) = 1,250
Total = 7,050
Submission date: October 27, 2012
ABSTRACT
Traffic Management System (TMS) is one of the most effective tools to control congestion in urban areas as it aims to eliminate congestion through application of advanced technologies. As a result of evolving socioeconomic status of the urban areas, the demand for mobility and transportation is increasing. Likewise, traffic management needs are shifting to new directions to meet emerging mobility needs. Advancements in traffic detection, information technology and computing efficiency offer great potentials for improving the functionality of Traffic Management System. However, identification of the potential directions for improvements requires revisiting the needs for traffic management, evaluation of the existing deployments and envisioning the future needs. This article is an effort to evaluate the emerging needs and possible improvements for Traffic Management System. Examples of the Traffic Management System deployments in Asia, Europe and North America were reviewed and compared in terms of the system provider, input data requirements, ITS technologies and system outputs. Major issues and challenges of existing practices were investigated and emerging traffic management needs for various system users were highlighted from the viewpoint of traffic operations and planning. Feasibility of implementing new technologies in Traffic Management System was evaluated and possible directions for improvements were discussed.
INTRODUCTION
Traffic congestion and mobility issues remain among the biggest challenges urban areas face in the 21st century. Congestion not only limits mobility, but also has adverse effects on economy, environment and safety. Traffic Management System (TMS) is one of the most effective tools to control congestion in urban areas as it aims to mitigate congestion and its impacts through application of advanced technologies. The socioeconomic status of the urban areas is evolving as a result of rapid growth which culminates in higher demand for mobility and transportation. Likewise, traffic management needs are shifting to new directions to meet emerging mobility needs. Advancements in traffic detection, information technology and computing efficiency offer great potentials for improving the efficiency and functionality of TMS. However, identification of the potential directions for improvements requires revisiting the needs for traffic management, evaluation of the state of practice and envisioning the future needs. This article aims to evaluate the emerging needs and possible improvements for TMS.

After a brief introduction, examples of TMS deployments in Asia, Europe and North America are reviewed and compared in terms of the system provider, input data requirements, ITS technologies and system outputs. Major issues and challenges of existing practices are investigated and emerging traffic management needs from the viewpoint of traffic operations and planning are highlighted for different system users and stakeholders. Finally, feasibility of applying new technologies in TMS is evaluated and some possible directions for improvements are discussed.

THE NEED FOR TMS
TMS scope is defined based on interactions between potential user needs, challenges and emerging technologies as demonstrated in FIGURE 1. The feasibility assessment begins with identifying the potential users and stakeholders of the system. While the most dominant beneficiary is the general public, system users and stakeholders include a wide range of private and public agencies and organizations such as transportation organizations, Police and emergency medical agencies. Each group of users or stakeholders has particular expectations and needs which should be met by TMS. For instance, the general public may be interested in pre-trip travel information while for the Police and transportation organizations incident response and management has a higher priority.

Often it is not practical to meet all potential user needs due to the limitation of data, technological barriers or inefficiency of existing analysis tools and algorithms. However, emerging technologies such as new data collection methods, improved computing efficiency and ongoing R&D efforts provide a strong leverage for tackling the challenges and pushing the limits.

TMS CLASSIFICATION
TMS scope and coverage may vary significantly. The network size covered by TMS may range from a particular corridor to a national road network. Regardless of the network size, a well-established TMS has several components working together to maintain one or more of the following functionality levels:

Level I-Basic functionality
The basic feature of any TMS is the capability to collect traffic data and monitor traffic conditions in real-time. Collected data are transmitted to Traffic Management Center (TMC), where data are processed and analyzed for further use. Traffic data are collected from multiple sources using appropriate detection devices and technologies such as in-road and roadside
detectors, video cameras, probe vehicles and cellular phones. Other data collection methods include reports from individuals, traffic Police, patrol cars and emergency crews. Depending on available traffic management options, various types of data might be collected such as traffic volume and speed, travel time, weather information, and incident and queue data. Traffic data are processed and traffic conditions are monitored autonomously in TMC. The processing includes data cleansing and validation, treatment of missing data and statistical operations such as data fusion and aggregation. Traffic events such as queues and incidents are detected either directly from real-time data feeds or indirectly by examining processed data against incident and queue detection algorithms. Detected incidents might require verification by video cameras or other mechanisms. To provide better insight into overall conditions traffic conditions are usually visualized on the map through a Graphical User Interface (GUI) so as system operators would be able to monitor multiple events dynamically.

**Level II-Extended functionality**

Extended functionality includes responding to the events and controlling the traffic based on the data collected in real-time. Under this category, TMS is capable of generating automatic responses (while enabling manual interventions) based on observed traffic conditions, traffic management options and TMS scope. Variety of responses may be generated ranging from sophisticated area-wide traffic signal control strategy to a simple display of travel time on a Variable Message Sign (VMS) along a freeway. Automatic responses require operator’s confirmation to be executable. Depending on the response type, different types of media (e.g. Internet, radio), communication devices (e.g. VMS, car navigation system) or traffic control devices (e.g. traffic signal) are used for dissemination of traffic information or enforcement of a traffic management strategy. A significant portion of traffic control and response management efforts are dedicated to post-incident response and traffic management activities such as
dissemination of incident data and related warnings to the road users, quick dispatch of Police and rescue personnel to clear accidents and temporary lane closure near the incident site.

**Level III- Advanced functionality**
Advanced functionality consists of a group of coordinated actions deployed beforehand in order to eliminate or control the extent of a traffic event (e.g. congestion, traffic accident) prior to its occurrence. Active Traffic Management (ATM) is a good example of level III functionality. Some of the technologies used in ATM include variable speed limit, dynamic lane operations and hard shoulder use during peak hours which aim to improve travel time reliability and eliminate the likelihood of traffic breakdown and accidents. Level III is the most challenging and technologically demanding functionality which is implemented only in few TMS deployments.

**STATE OF PRACTICE: TMS AROUND THE WORLD**
The evaluation of potential directions for improvement of TMS requires comprehensive evaluation of state of practice. This section investigates some example TMS deployments around the world.

**Asia**

**Japan, Tokyo**
Traffic management and administration in Japan is lead by National Police Agency (NPA) which established TMS in Japan over the past four decades. Japan is the only country in the world where full Advanced Traffic Management Systems (ATMS) is approaching the status of an established industry. Japan is investing more than $6 billion to equip its 30 largest cities with full ATMS in the next 10 years (1).

**Traffic Management in Tokyo**
In accordance with the national standards, roads in Greater Tokyo Area are divided into two broad categories with different traffic management system and control strategies: local and regional highways, and the expressway network.

**Local and Regional Highways** Local and regional highways consists of national, prefectural and metropolitan, and local roads where traffic is managed by a dense network of centrally coordinated traffic signals. Traffic information are collected through 17,000 vehicle detectors, surveillance cameras, Police cars, helicopters and reports, and sent to Tokyo Traffic Control Center, for further processing and monitoring. The central display board at Tokyo Traffic Control Center highlights 1,000 intersections, and has 15,154 traffic signals in the system. When traffic jams are detected or reported, the affected area turns from green to red. It also displays traffic accidents and closed streets. Information is communicated to Tokyo residents live through radio reports and 300 VMS on the network. As an added functionality, a commander of the control center can manually adjust traffic signal timings for any of 7,000 of traffic lights, and communicate directly with traffic officers in the field (2).

Tokyo Metropolitan Police Department is in charge of setting traffic signals in Tokyo. Traffic signal coordination and offset control is accomplished through dynamic simulation using TRANSYT (3). Usually, a signalized corridor is divided into several sub-areas based on traffic demand and the distance between consecutive intersections. Based on the information received from traffic detectors, sub-areas are set roughly and the offset is set for each sub-area. Pattern selection method is used to choose appropriate offset for each sub-area (4). Traffic signal design...
method in Japan has changed from pattern selection method to adaptive control method after 1995. However, for sub-area design and offset control, pattern selection method is still in practice. The main reason is the adaptive offset control and sub-area design requires a very powerful and fast real-time simulator which is not available yet (3).

Expressway Network  In Tokyo, a significant portion of daily traffic is carried out by a network of toll roads including elevated expressways and ring roads managed by Tokyo Metropolitan Expressway Corporation. Traffic data and accident information are received through vehicle detectors, patrol cars and traffic control cameras. Traffic information is processed in traffic control center and useful information such as traffic conditions, route information and travel time are provided to drivers in real-time through VMS and Internet.

Tokyo metropolitan expressway network is equipped with Electronic Toll Collection (ETC) System which could significantly eliminate congestion at toll booths. Implementation started in March 2000 and by 2010 ETC usage in Tokyo metropolitan expressway exceeded 88% which is exceptionally high. Another unique feature of TMS in Tokyo metropolitan expressway network is Advanced Tunnel Disaster Prevention (ATDP) System which has been installed to assist drivers and guide them in the event of an emergency in tunnels. ATDP includes traffic signals and entry barriers to control incoming traffic to tunnels in emergency (5).

National Traffic Management
Nationwide traffic information communications in Japan is carried out by VICS. Established in 1995, VICS aims to eliminate congestion, reduce traffic accidents, and improve road environment. VICS provides travel time information up to the next interchange, congestion information and turnoff guidance (including alternative parallel routes) and, information on restrictions due to accidents, disabled cars, construction, disasters and weather conditions (road blockage, lane regulations, speed limits, chain regulations in winter, etc.). To receive VICS information, vehicles should be equipped with VICS compatible car navigation unit and a FM multiplex reception antenna. VICS systematically collects traffic information from road administrative agencies and prefectural Police headquarters. The VICS center provides real-time road traffic information to car navigation systems using three types of media:

- Radio wave beacons; installed mainly on expressways, providing road traffic information in a range of approximately 200km ahead of the car.
- Infrared beacons; installed on main ordinary roads, providing road traffic information as far as 30km ahead of, and 1km behind the car; and
- FM multiplex broadcasting provides road traffic information in a particular prefecture and its surroundings from the local Japan Broadcasting Corporation (NHK) FM broadcasting stations.

Depending on the type of car navigation unit VICS provides map display, simple graphic display and text display in real-time. The information received will vary according to the car location and capabilities of the car navigation unit (6).

Other examples in Asia
South Korea, Seoul
The first Freeway Management System (FTMS) in Seoul has been established in 1997 by LG CNS (6) and expanded to major expressways in order to alleviate recurring and non-recurring
congestion through computerized data acquisition and processing, incident detection and management, and dissemination of traffic information to the public. FTMS components in Seoul include:

- Traffic status surveillance and center operations system,
- Traffic data collection using Vehicle Detector Stations (VDS),
- Close Circuit Television (CCTV) cameras,
- Traffic control through ramp metering stations and lane control signs,
- Information service (VMS, Internet, Mobile); and
- Establishment of a traffic data warehouse for all areas with urban expressways.

In 2005, LG CNS established Seoul Transport Operation and Information Service (TOPIS) which is an integrated transportation center that collects traffic information from relevant authorities and many related sub-centers and manages traffic conditions and shares traffic data with Seoul residents. TOPIS disseminates traffic information through Traffic Broadcasting System, mobile phones, Internet, VMS, and serves as the core of Seoul’s TMS (7).

**China, Beijing**

Beijing’s initial TMS was launched in 1998. By the end of 2009, the resulting system included traffic detection on the ring roads, actuated signal control, GPS based digital Police positioning and dispatching, VMS and other information dissemination approaches (8). Beijing Traffic Management Bureau (BTMB) provides several services including real-time traffic monitoring, traffic control, and incident management. Beijing’s real-time congestion map is available through BTMB website.

Traffic detection and monitoring is achieved using thousands of loop detectors and hundreds of high definition cameras and video devices installed on expressways and the ring roads within Beijing’s urban area. The traffic monitoring system automatically compares current traffic patterns with the average of the previous four weeks and if traffic flow or congestion exceeds historical values, an alarm system will be activated automatically to inform the corresponding traffic management departments (8).

Actuated signal control systems have been installed in 1,535 intersections in different areas in Beijing. The signal control system which includes SCOOT (TRL), ACTRA (SIEMENS) and HiCon (HiSense Technology) technologies calculates the signal timings automatically based on the real-time information collected through traffic detectors and conduct the maximum passage control during the rush hours (8).

The incident management system automatically sends incident information to the nearest traffic Police station which significantly reduces the response time and the resulting non-recurrent congestion (9). The Decision Support System (DSS) for Beijing TMS was developed by Delcan and DHV Group between 2004 and 2010. With the help of the DSS, coordinated traffic management strategies and incident response measures can be implemented for the road network within Beijing. Subsequently, traffic conditions can be improved through the application of effective incident management and route guidance techniques (10).

**UAE, Dubai**

Dubai’s Roads and Transport Authority (RTA) regulates transportation within the city of Dubai. RTA invested in deployment of a new TMS to relief congestion in Dubai urban network. In 2007, Siemens installed the Freeway and Local Control Operations Network (FALCON) traffic control
management system in Dubai, which monitors and controls the road traffic by using monitoring cameras and video systems that automatically detect accidents and control more than 300 traffic signals on the main arteries. FALCON provides up-to-date information promptly by SMS and Internet. In 2011, the urban traffic control system of Dubai was upgraded to Siemens PC SCOOT technology (11, 12).

Israel, National Traffic Management System (NTMS)
The Israeli National Roads Company (Ma’atz) is the agency responsible for the construction, operation and maintenance of the inter-urban road network of Israel. Ma’atz has undertaken the supply, installation and operation of a NTMS. IBI Group is the overall system designer, integrator and software supplier of the NTMS. The NTMS covers 360 km of interurban highways, operates loop detectors, VMS, variable speed signs, and disseminates updated traffic information to drivers via SMS messages, emails, and a website. The NTMS is envisioned for detection, monitoring, tracking, and responding to events that impact traffic conditions, including: incidents, queues, adverse weather conditions, planned events, and unplanned emergency situations (e.g. severe accident that requires a road closure). For all cases, traffic events are managed in three steps:

- Detection; both automatic (based on live traffic data and incident and queue detection algorithms or through interfaces with external systems) and non-automatic (CCTV monitoring, external sources such as Police) are used to detect planned and unplanned events;
- Confirmation; generally by CCTV cameras, but sometimes from reliable sources (e.g. Police or Ma’atz District personnel) in the case where camera coverage is unavailable; and
- Response; provide motorist advisory and traveller information through the use of VMS, Lane Control Signs (LCS) and broadcast methods (e.g. fax, email, SMS and Internet), and provide the system operator with suggested signal and/or ramp meter timing plans to be implemented.

Europe
England, Birmingham
Active Traffic Management (ATM) which is also known as “managed lanes” or “smart lanes” is an established TMS solution in England. ATM tackles congestion by introducing new technology along with innovative solutions to make best use of the existing road space. ATM is currently in operation in different scales on several highways including M42 south-east of Birmingham. ATM employs a set of technologies Error! Reference source not found.and procedures to enable management of the traffic flow and dynamic use of the hard shoulder (13) which are presented in TABLE 1.

Traffic Management System
The technologies described in TABLE 1 can be combined in various forms to produce a managed motorway solution that suits a particular problem. The configurations which are currently in operation are presented in TABLE 2. ATM technologies, particularly the ability to display different signs over different lanes, offer the potential to implement other advanced traffic management initiatives in the future (13).
M42 ATM pilot

In 2006, Highways Agency launched hard shoulder running trial on the M42 between junctions 3A and 7, to the south-east of Birmingham. This section of the M42 has high traffic flows and encompasses interchanges for the National Exhibition Centre and Birmingham International Airport, with very significant peak period commuter flows. The site has distinct morning and evening peaks which suited the dynamic operation of the hard shoulder.

The M42 pilot provided the opportunity to demonstrate and test a number of dynamic traffic management tools. M42 ATM Monitoring and Evaluation report (14) documented several benefits of M42 ATM pilot:

- An extra 7% of users encountered no congestion on the M42 ATM section in 2007 compared to 2003
- ATM reduced average travel times by up to 24% in the northbound direction and 9% in the southbound direction
- Travel time variations reduced by 22%
- The overall isolated effects of ATM on emissions from all vehicles were:
  - Carbon-monoxide (CO) reduced by 4%
  - Particulate Matter (PM) reduced by 10%
  - Hydrocarbons (HC) increased by 3%
  - Carbon-dioxide (CO₂) reduced by 4%
  - Oxides of Nitrogen (NOₓ) reduced by 5%; and

### TABLE 1 ATM technologies

<table>
<thead>
<tr>
<th>ATM Technology</th>
<th>Application</th>
</tr>
</thead>
</table>
| Automatic queue detection and signaling| - Provided through Motorway Incident Detection and Automatic Signaling (MIDAS)  
- Uses inductive loops detectors to detect slow moving, queuing or stationary traffic, |
| CCTV                                   | - Provides regional control centers with real-time traffic and incident information                                                        |
| Advanced motorway indicators           | - The latest form of light emitting diode (LED) signs  
- Display mandatory variable speed limits above lanes  
- Can be used to open and close the hard shoulder or any of the other lanes |
| Semi automatic control system          | - A software based process  
- Leads traffic control operators for inspecting sections of the hard shoulder for obstructions via CCTV prior to opening it as a running lane |
| Highways Agency Digital Enforcement Camera System (HADECS) | - Using radar based speed detection to enforce the mandatory variable speed limits associated with schemes such as hard shoulder running.  
- When in operation, all evidence is automatically retrieved and recorded at a secure Police office |
| Message signs                          | - Two-color message signs able to display text, pictures and signals flexibly,  
- Uses LED technology  
- Can be set either by an operator or automatically |
| Ramp metering                          | - Uses traffic lights on motorway entry slip roads to regulate the flow onto the motorway                                                   |
• Fuel consumption reduced by 4%

**TABLE 2 Managed motorway solutions in ATM**

<table>
<thead>
<tr>
<th>Scope</th>
<th>Solution</th>
<th>Concept</th>
<th>Applied technology</th>
</tr>
</thead>
</table>
| Operating      | Hard shoulder running | - Drivers are permitted to use the hard shoulder of the motorway as a running lane at times of high congestion  
- A 50mph speed limit is introduced to all lanes  
- Speed limit is displayed above each lane  
- When hard shoulder not in operation, variable speed limits are in force on other lanes | - CCTV  
- MIDAS  
- HADECS  
- Ramp metering |
|                | Controlled motorway    | - To minimize the risk of flow breakdown and accidents  
- To produce more reliable travel times  
- Mandatory speed limits are set automatically  
- Speed limits of 60mph and 50mph are enforced by using automatic camera technology to address congestion  
- When it is necessary to protect traffic from queues, speed limit is set lower at 40mph | - MIDAS  
- Loop detectors  
- HADECS  
- CCTV |
|                | Basic controlled motorway | - Deployed on 2 or 3 lane sections of the network  
- Operates in two modes: for congestion management or incident management  
- In congestion management mode, the system would set mandatory 50mph speed limits using gantry signaling at the entry and exit of each section  
- If there is an incident, the system would be switched to incident management mode  
- In incident management mode, the driver information signs would display warnings only (e.g. "QUEUE AHEAD") and not speed limits  
- In incident management mode, the speed limit signs set on gantries upstream of the incident location would remain in force | - MIDAS  
- Loop detectors  
- HADECS  
- CCTV |
| Potential      | Traffic segregation    | - High Occupancy Vehicle (HOV) lanes  
- Bus-only lanes  
- HGV (Heavy Goods Vehicle) /climbing lanes | - Advanced motorway indicators  
- Message signs |
|                | Lane based speed limits | - Aims to improve vehicle throughput and safety | - Advanced motorway indicators  
- Message signs |
|                | Digital roadside communication | - Installation of roadside beacons for communication with equipped vehicles | - Roadside beacons and in-vehicle devices |
|                | Information monitoring and recording | - Image recording for the purpose of monitoring the traffic management system, individual lane use, or enforcement of traffic offences | - HADECS  
- CCTV |
Other examples in Europe

Greece, Athens
TMS in Athens was established by Siemens in June 2004 prior to Athens Olympics. The project was funded by the Ministry of Public Works. Siemens installed its SITRAFFIC Concert, and SITRAFFIC Central (15, 16) to achieve a universal TMS in Athens.

The system is operated from two control centers (one used as backup) fed with data from a variety of sources including CTV cameras, traffic signals, video-detection cameras, ground loop detectors, speed radar devices and security personnel and traffic Police on the ground. The system can analyze and process the information it receives and then display traffic conditions using a GUI. The decision-making algorithms programmed into the TMS can then determine how best to handle the problems. The system can act automatically via VMS on the road side, by adjusting the phase and continuity of traffic signals and by alerting traffic Police on the scene. In this way Athens famous grid-lock traffic jams were avoided during the Olympics (17).

City-FCD (Floating Car Data) is a state-of-the-art system that was integrated into the Athens TMS in summer 2004 to aid in the movement of fleets of Olympic vehicles through busy traffic situations. It works in conjunction with the aerial monitoring of the airship above the city, which could function independently if required. FCD technology allows official vehicles such as Police cars or emergency services to act as sensors to allow the continuous, real-time recording of a current traffic situation and to form the core of traffic data acquisition. If a vehicle equipped with City-FCD reports a traffic jam, the airship will be directed to the area to monitor the traffic situation. (17).

North America

Canada, Toronto
Traffic management in Ontario highways is carried out by MTO (Ministry of Transport-Ontario). COMPASS is a FTMS deployed by MTO to respond to traffic congestion problems on urban freeways. COMPASS helps reduce traffic congestion and increase safety by allowing for the prompt detection and removal of freeway incidents and vehicle breakdowns, providing accurate and timely freeway incident and delay information to motorists and effectively managing peak rush hour traffic flow through innovative traffic control devices. COMPASS was first implemented in 1999 to manage traffic on Highway 401 in Toronto and has been continuously evaluated, enhanced and expanded over the years. Currently it covers more than 110 km of highways in Toronto area (18).

Detection and confirmation
Detection of traffic congestion is primarily accomplished through the use of loop detectors embedded in the freeway pavement at approximately 600 meters intervals which transmit traffic data back to the Traffic Operations Centre (TOC) every 20 seconds. A central computer at the TOC constantly analyses the data using an incident detection algorithm and alerts the operator of a suspected incident and request a confirmation. CCTV cameras provide the primary means of confirmation. These cameras are placed about one kilometer apart with full pan, tilt, and zoom capabilities, effectively providing 100% coverage of the roadway. Once the incident is confirmed visually, the operator will proceed with a specific response plan and notify the appropriate response services (19). The primary incident detection algorithm used by MTO is McMaster algorithm (20).
Incident management
COMPASS system transmits incident data to TOC that also receives all road condition, construction and maintenance activity reports. Due to the abundance of information available, TOC can often play a major coordinating role in incident management situations. Ontario Provincial Police personnel are key players in a large portion of incident management activities and their response time is critical. Early detection of problems through the COMPASS system allows for easier and more efficient coordination of response activities (19).

Motorist advisory
COMPASS system uses VMS located prior to strategic diversion points where motorists can choose between alternate routes. Within seconds of the confirmation of an incident, the central computer recommends a specific set of signs and messages based on the location and nature of the incident. The operator must review and approve the response plan before the messages are dispatched to the signs. In addition, the Traffic Operations Center staffs in Toronto COMPASS System operate a Traffic and Road Information System (TRIS) covering all provincial highways within the Greater Toronto Area and the Niagara Peninsula. Traffic reports are automatically faxed to the media and emergency services (19).

Congestion management
Regardless of whether congestion is being caused by an accident or normal rush hour traffic, the VMS are capable of automatically displaying information related to the level of congestion on the freeway. In the Toronto COMPASS System, the messages describe the average traffic conditions on the express and collector lanes for a pre-defined upcoming section of the freeway. The average traffic condition is defined in terms of "MOVING WELL" (75 km/h and above), "MOVING SLOWLY" (40 to 75 km/h), and "VERY SLOW" (less than 40 km/h). Motorists may use this information to decide whether to continue travelling on their original route or take an alternate route by transferring onto the express or collector lanes. This traffic information can help balance the traffic flow, maximize roadway capacity usage, reduce motorist travel times, and improve safety on the freeway (19).

Other examples in North America
USA, Kansas City
Kansas City Scout (KC Scout) is Kansas City's bi-state TMS launched in 2002 by Kansas and Missouri departments of transportation (KDOT, MoDOT). Developed by Delcan, KC Scout manages traffic on more than 125 miles of continuous freeways in the greater Kansas City metropolitan area integrating CCTV cameras, VMS, VDS, highway advisory radio (HAR) system, and a dynamic web site. KC Scout has no traffic control capabilities, but it can detect and manage various traffic situations on its system. KC Scout provides real-time travel time information to help motorists to decide early in their commute if they should choose an alternative route because their intended route is too congested.

KC Scout's incident management program coordinates the resources of public agencies and private sector partners to detect, respond to, and remove traffic incidents in a way that gets traffic moving again as safely and quickly as possible. The program has resulted in shorter accident clearance times and fewer accidents related to congestion. In 2009 freeway lanes were closed 201 fewer hours because of accidents than in 2006 (before the program began). Specifically, lanes were closed an average of 15.82 minutes per accident in 2006 with 980 accidents while lanes were closed for just 14.91 minutes per lane in 2009 with more than twice as many accidents at 2,315 (21).
ISSUES AND CHALLENGES

TABLE 3 and TABLE 4 summarize the results of the TMS deployments review. The most common data collection devices are loop detectors and CCTV cameras and all reviewed systems relay on VMS to disseminate traffic information. Another basic feature of reviewed TMS deployments is incident detection and automatic response management. The functionality of the majority of reviewed TMS deployments is limited to Level I and Level II. Based on the review results, only TMS deployment in Tokyo offers full extended functionality (Level II) and advanced functionality (Level III) is provided only partially in ATM deployment in M42. Level III functionalities such as variable speed limit, hard shoulder use, dynamic lane operations require sophisticated equipments and technical arrangements (e.g. to meet safety concerns) which explains why such solutions are not widely implemented.

TABLE 3 Summary of reviewed TMS deployments

<table>
<thead>
<tr>
<th>a) TMS providers and operators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deployment</td>
</tr>
<tr>
<td>Asia</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Europe</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>North America</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>b) ITS technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deployment</td>
</tr>
<tr>
<td>Asia</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Europe</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>North America</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
In most of the current practices the role of traffic management is reduced to response management to events (e.g. queue response plan, incident response plan). In other words, the system waits until an event occurs, then observed traffic conditions are considered and responses are generated and implemented. As a result, responses are more informative rather than preventive. However, it is more essential to initiate actions to prevent congestion and traffic accidents before they occur. Implementation of preventive measures cannot be achieved without improving TMS functionalities in all levels which are discussed in the following section.

**POTENTIAL DIRECTIONS FOR IMPROVEMENT**

There are great potentials for improving the functionalities provided by TMS in all levels. For each functionality level, some possible directions for improvements are discussed hereafter.

**Level I-Basic functionality**

Loop detectors and video cameras are the most conventional sensor technologies used in traffic surveillance. However, in parallel to recent advancements in traffic surveillance and detection technology, new traffic data sources are emerging. For instance smart phones with GPS and Internet access are becoming an important source of information used to provide traffic data. Connected vehicle technology is another emerging method for collecting real-time traffic data. Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) data transmission provides a
connected data-rich travel environment. Real-time data are collected using equipment located on-board vehicles (automobiles, trucks, and buses) and within the infrastructure. The data are transmitted wirelessly and are used by transportation managers in a wide range of dynamic, multi-modal applications to manage the trans portation system for optimum performance (22). As reflected in survey results, V2I data transmission is well established in Japan. Development of more accurate queue and incident detection algorithms is another potential direction for improving TMS. Performance of an incident detection algorithm depends on several factors including road geometry, required input data and aggregation interval, sensor type and configuration, and traffic disturbance factors. Transferability and low detection rate are the main issues that limit the application of incident detection algorithms. As a result, witness reports and CCTV are still the principal means of incident detection and verification (23).

**Level II-Extended functionality**
Dissemination of traffic information and responses to traffic events is generally handled through VMS. Communication through VMS is limited as VMS locations are pre-defined. To support road users to make informed decisions about their departure time, travel route and route diversion, traffic event data and response plans should be disseminated well enough ahead of time. Implementation of connected vehicle technologies can significantly improve Level II functionality as road users can immediately receive the information of traffic incidents, expected delay and alternative routes through on-board devices. Connected vehicle technologies also increase situational awareness and significantly reduce the risk of traffic accidents by supporting driver advisories, driver warnings, and vehicle and/or infrastructure controls (22).

**Level III-Advanced functionality**
Road users have relatively fair perceptions about their trip’s expected travel time based on which they schedule their trip. However, incidents such as special events, accidents, work zones and vehicle breakdowns may disrupt presumed traffic conditions, where subsequent non-recurrent congestion leads to unprecedented delays. Post-incident delays expose road users to massive financial losses considering the value of time for commercial vehicles and the general public. As a result, TMS functionality which enables prediction of the future traffic conditions is highly demanded by transportation agencies and the road users. For transportation agencies, short-term prediction of traffic conditions is significant for efficient handling of traffic operations. On the other hand, for planning and construction departments, less detailed yet long-term traffic prediction is significant for evaluation of the impacts of road works, lane closures and road construction. Addition of traffic prediction functionality to TMS is challenging in various ways. For short-term prediction the system requires an efficient online simulation engine which is fed by real-time data continuously. Long-tem prediction capability on the other hand requires the knowledge of OD matrix and a realistic assignment model. Required computing power and data needs are challenging in particular for large networks. Availability of traffic information from multi sources (e.g. fixed and probe sensor data) makes it possible to employ the analytical models to predict traffic conditions (24, 25). On the other hand, emerging computation techniques such as parallel computing and cloud computing facilitates the development of comprehensive simulation modules for real-time traffic prediction.
CONCLUSIONS AND RECOMMENDATIONS
Examples of TMS deployments in Asia, Europe and North America were analyzed and compared in term of their features and functionalities. TMS deployments were classified into three levels based on their functionalities:

- Level I- Basic functionality; limited to real-time data collection and monitoring
- Level II- Extended functionality; includes responding to the events and controlling the traffic based on the data collected in real-time, and
- Level III- Advanced functionality; consists of a group of coordinated actions deployed beforehand in order to eliminate or control the extent of a traffic event.

Review results demonstrate that the functionality of the majority of example TMS deployments is limited to Level I and Level II. Only TMS deployment in Tokyo offers full extended functionality (Level II) and advanced functionality (Level III) is provided only partially in ATM deployment in M42. In majority of TMS deployments, the role of traffic management is reduced to response management to events where the system waits until an event occurs, and then responses are generated and implemented. As a result, generated responses are often not preventive. The significance of implementing preventive measures to eliminate the risk of congestion and traffic accidents were highlighted. Implementation of preventive measures requires traffic prediction capabilities, efficient communication technologies and technical equipments. Availability of new data sources, connected vehicle technologies and analytical and simulation tools provide great opportunities to tackle these challenges.

ACKNOWLEGMENT
Author would like to thank Dr. Mohamed Wahba for providing constructive comments and suggestions.

REFERENCES